Paraffin Actuated Heat Switch for Mars Surface Applications

Eric Sunada[1], Mike Pauken[1], Kurt Lankford[2],
Keith Novak[1], Gajanana Birur[1]

July 15, 2002

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Starsys Research Corporation

Overview

- Background
- Key Driving Requirements
- Paraffin Actuated Heat Switch
  - Heat Switch Design Features
  - Heat Switch Performance
  - Flight Qualification
- Mars Exploration Rover (MER) Application – Rover Battery
  - Rover Battery Thermal Control System
  - Thermal Control System Performance
- Summary

Background

- Unique Thermal Control Requirements for Mars Surface Applications
  - Diurnal temperature changes greater than 100 °C Δ
  - Presence of Mars atmosphere
  - Need to minimize landed mass
  - Power for active thermal control is scarce
    - Need to conserve energy at night
  - Need to reject excess heat during the day
- Thermal Control System for Mars Exploration Rover (MER) Battery
  - Relatively narrow allowable flight temperature limits [-20 °C, +30 °C]
  - Total heat needed to be rejected ~8 to 12W

Background

- Based on the requirements, a decision was made to use a variable thermal conductance device

- Paraffin Actuated Heat Switch
  - Passive, variable thermal conductance mechanism which can be mounted between a heat sink (external radiator) and heat source (Rover battery assembly)
  - Variable thermal conductance achieved via temperature activated paraffin wax which expands/contracts to mechanically close/open the switch

Key Design Requirements

Requirement Description	Value
Switch-Open Conductance	< 0.018 W/K at 18 °C and lower
Switch–Closed Conductance	> 0.45 W/K at 25 °C and higher
Heat Switch Assembly Mass	< 160 g
Landing Loads (qualification)	48 Gs
Random Vibration (qualification)	7.8 Grms, 2 min./axis (20-80 Hz: +6db/Oct. 80-450 Hz: 0.08 G^2/Hz 450-2000 Hz: -6db/Oct.)
Pyroshock (qualification)	100 Hz: 20 g srs 100-1600 Hz: +10 db/Oct. 1600-10000 Hz: 2000 g srs

Paraffin Actuated Heat Switch

Heat Switch Shown in Closed State

Attached to heat source

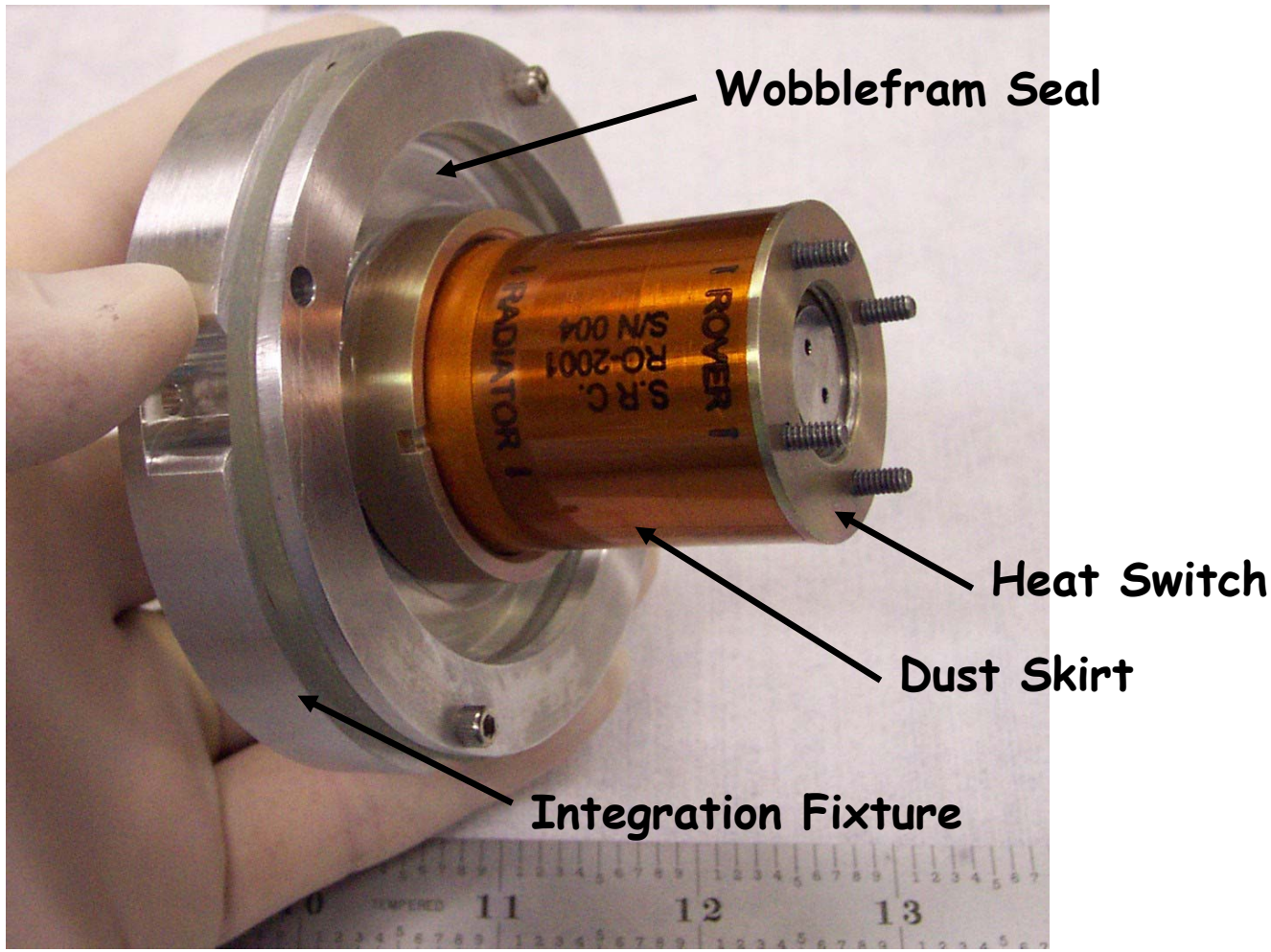
Switch half containing paraffin seal boot

In switch-open state, 1mm gap separates the two switch halves

Attached to radiator

Paraffin Actuated Heat Switch with Integration Fixture and Dust Skirt

Heat Switch Shown in Closed State



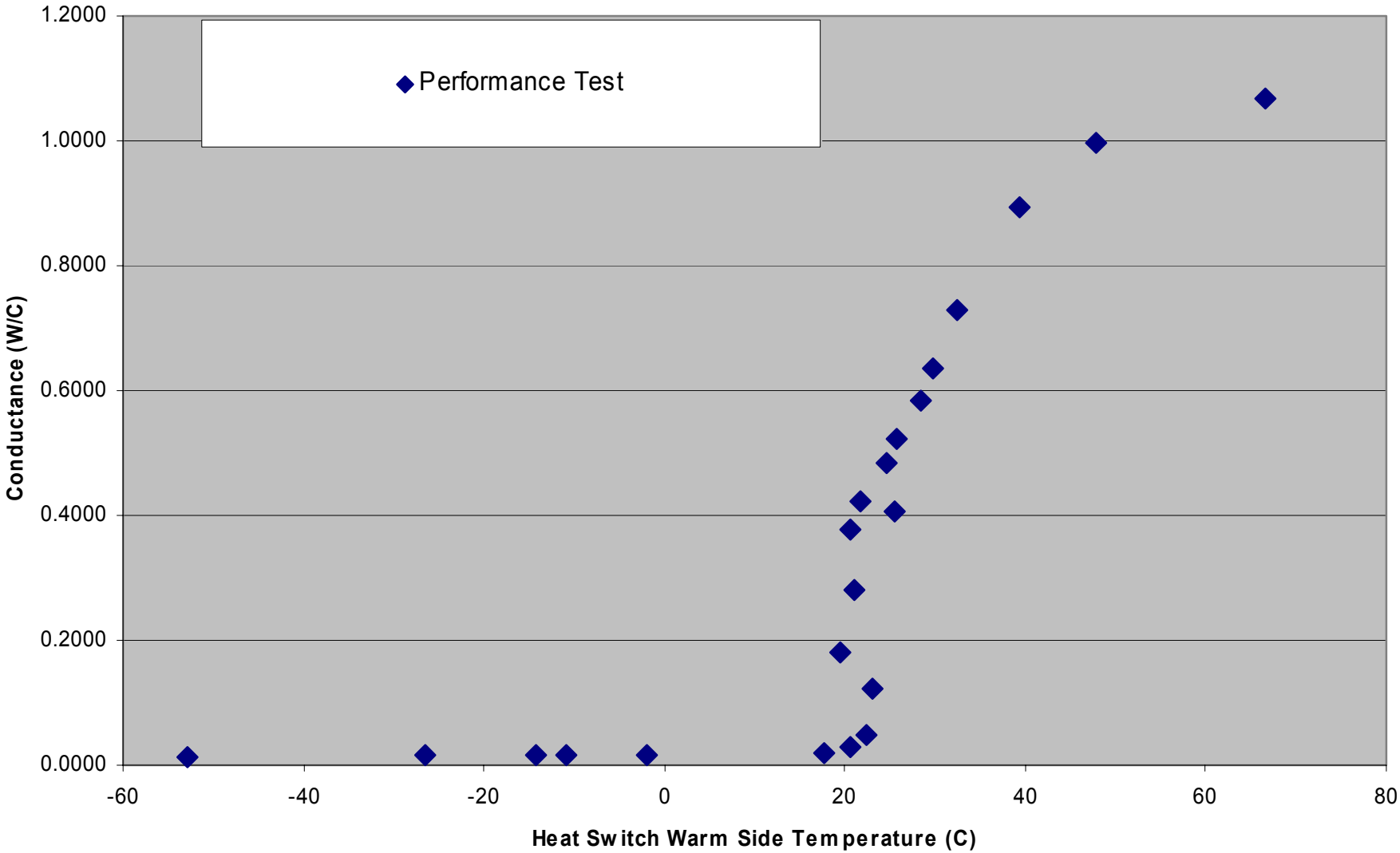
Paraffin Actuated Heat Switch

- Design Features
  - Developed by Starsys Research Corporation for JPL
    - Based on previous designs by Starsys with modifications to accommodate the Mars environment
  - About 36 mm diameter x 51 mm in length
  - Aluminum body
  - Entire switch mass ~ 110 grams
  - Molded Viton seal encloses paraffin
  - Temperature based expansion and contraction of the paraffin works to close and open the switch, respectively
    - switch activation temperature is selectable based on paraffin type
  - Springs with insulating stand-offs provide force to open gap when paraffin freezes

Paraffin Actuated Heat Switch

- Design Features (cont'd)
  - Control is not simply by On-Off switching
    - thermal conductance adjusts to stable intermediate levels as required
  - Switch control is based on the temperature of the warm side of the switch
  - In switch-open state, two halves of switch are separated by 1mm gap
    - heat conduction is limited to gas gap conduction and small parasitic leaks through stand-offs
  - In switch-closed state, the halves are pulled into contact with each other
    - heat is conducted through aluminum body across contacting surface

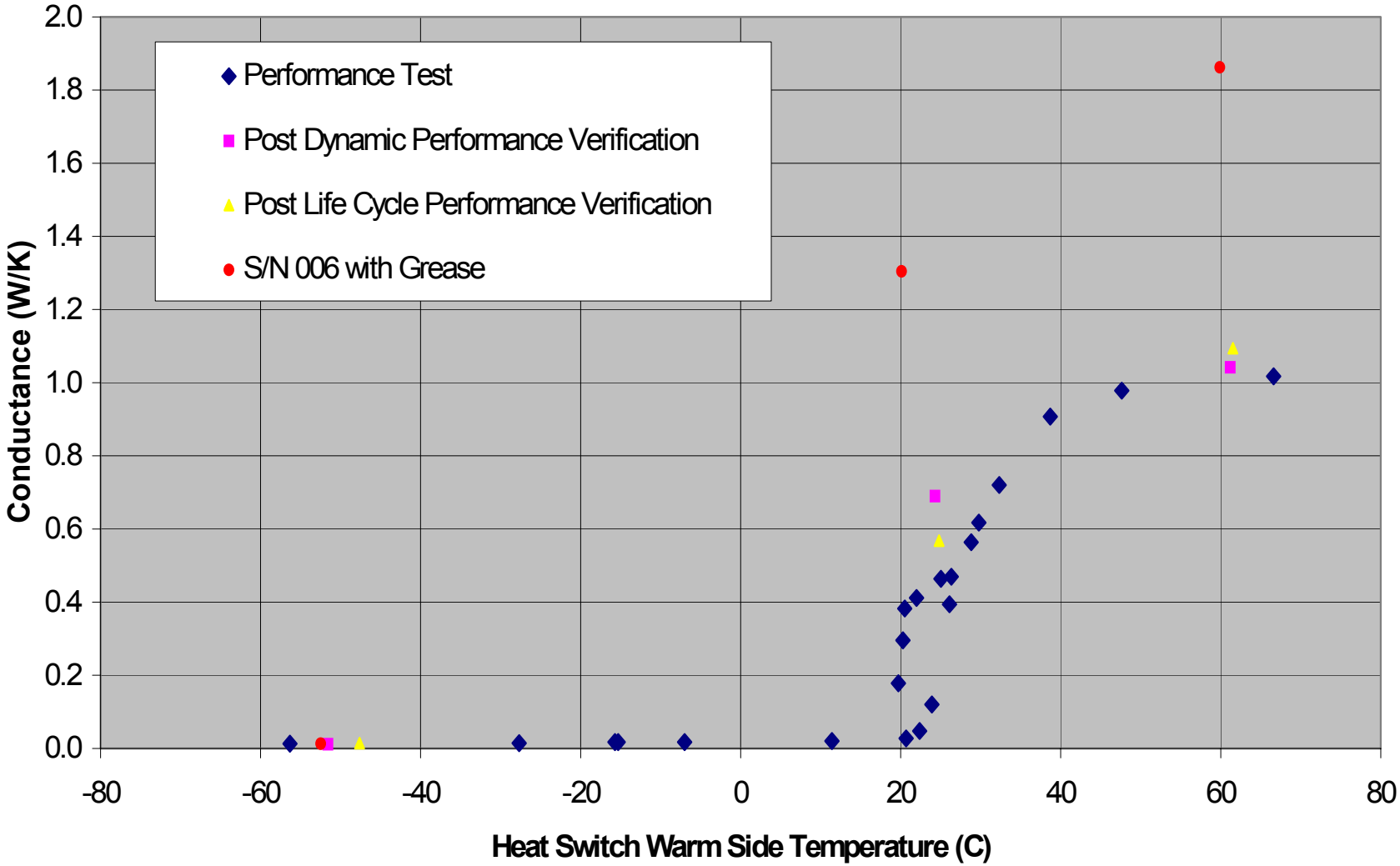
Heat Switch Performance – Qual Test Results, S/N 005



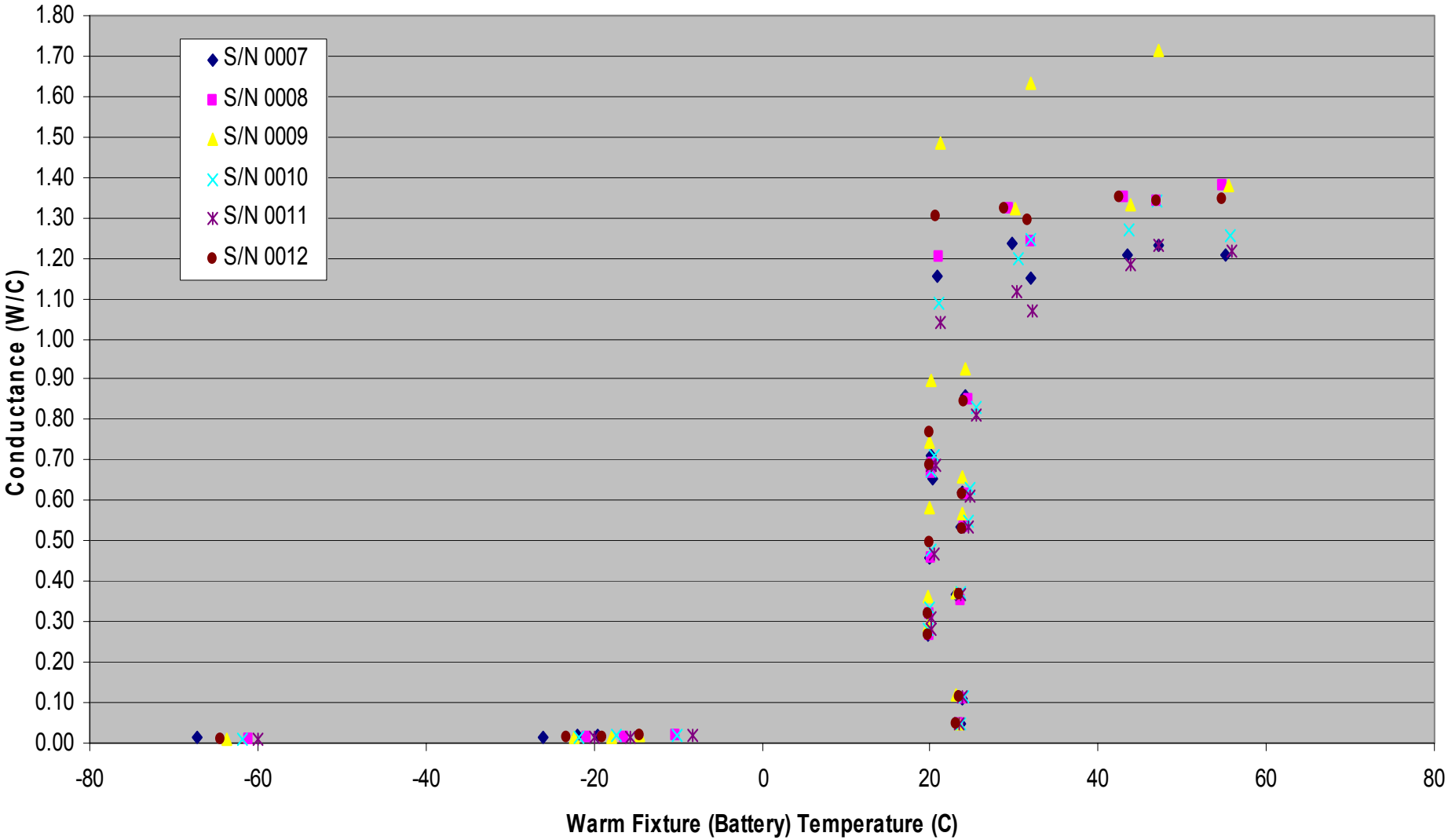
Mitigation of Cold Welding

- Although chance of occuring are remote, required to mitigate the possibility of cold welding the two aluminum switch halves
  - During surface operations, Martian atmosphere precludes the possibility of cold welding
  - During most of cruise phase (vacuum environment), switch will be in the open condition
  - During launch and the earliest part of cruise phase, switch will be in the closed condition – remote possibility of cold welding
- Mitigating Options
  - Option 1: Hard anodize one of the contactding surfaces
  - Option 2: Grease plate the interface

Heat Switch Performance – Qualification Units



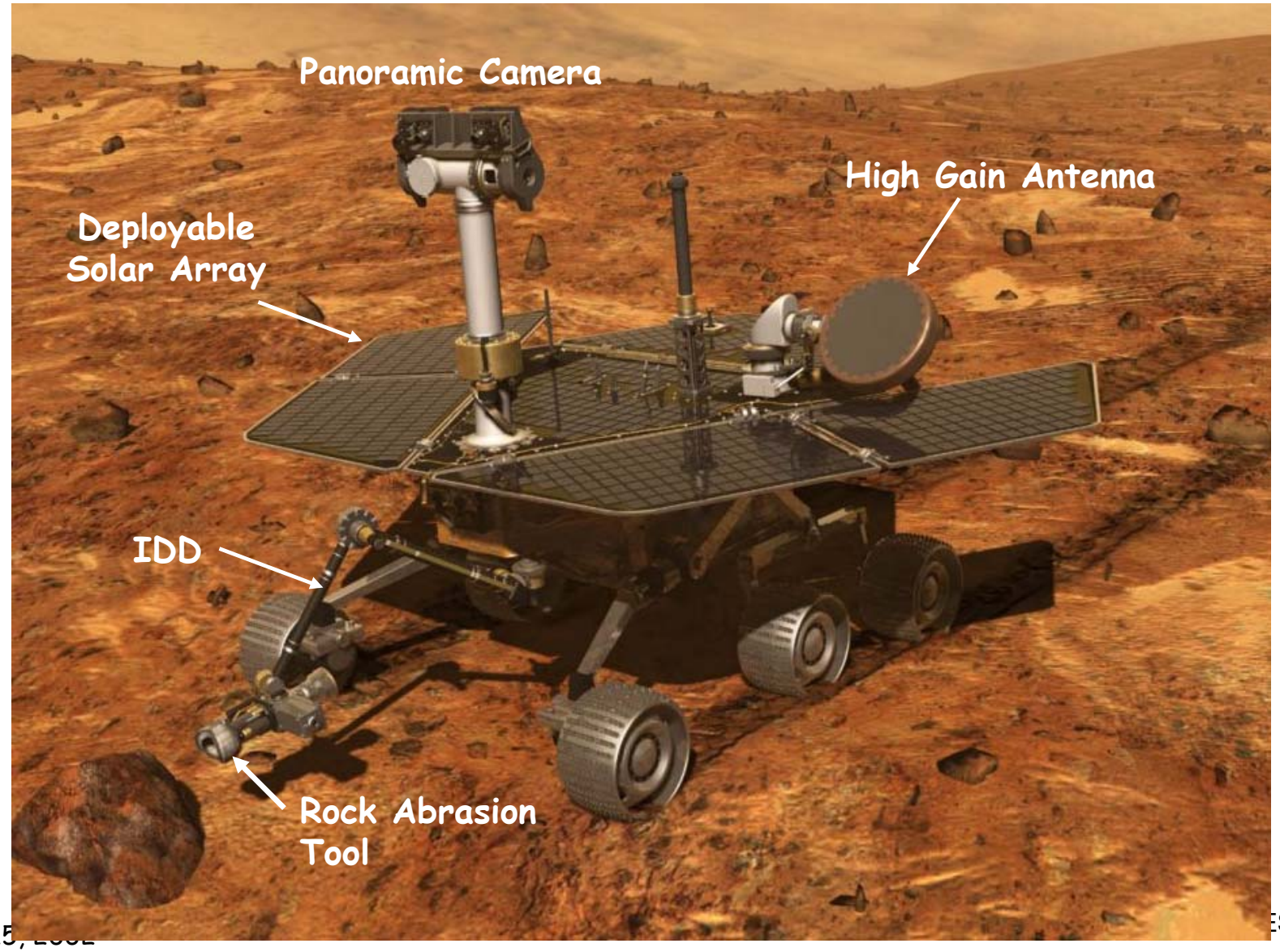
Heat Switch Performance – Flight Units



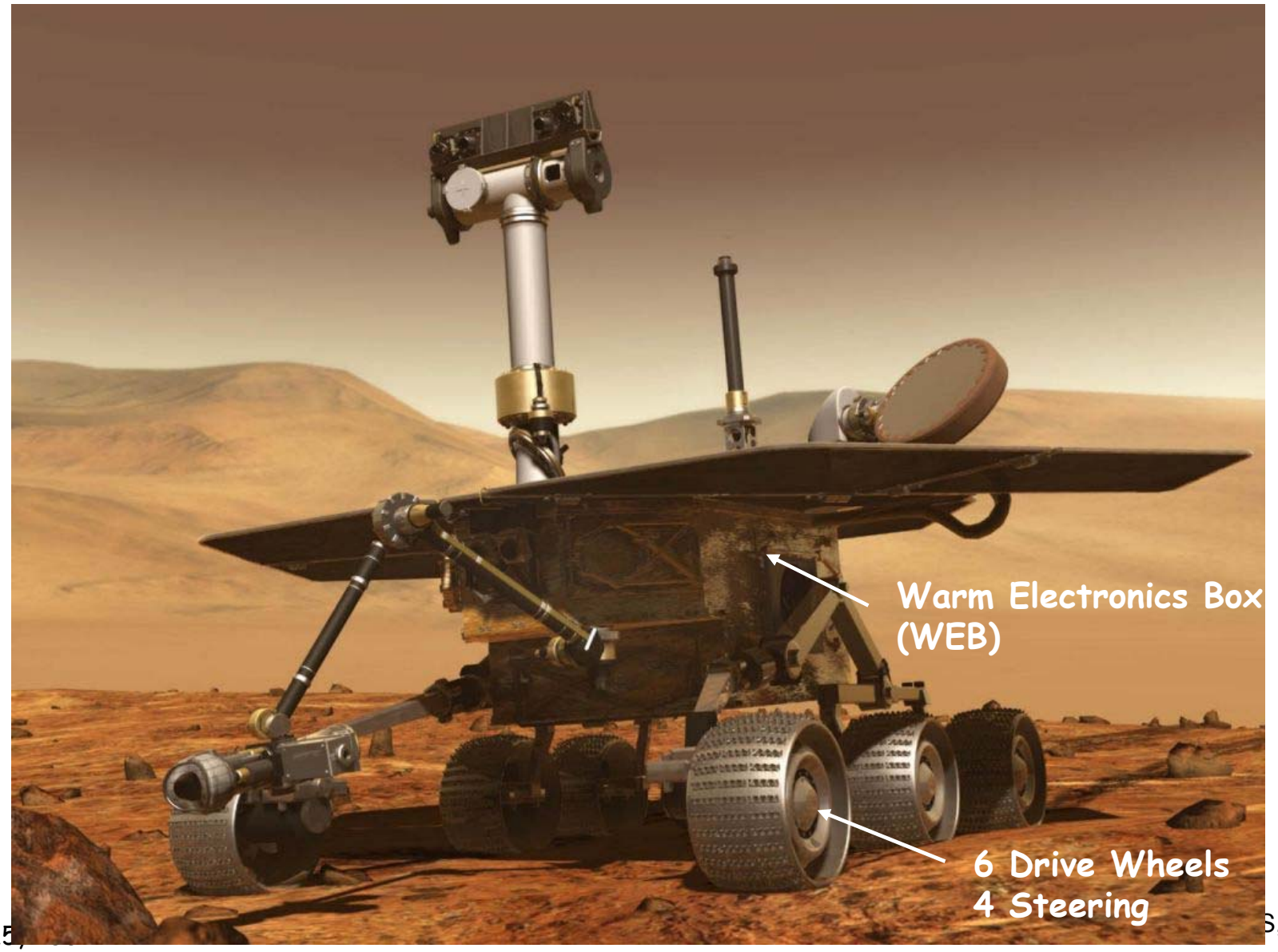
Qualification Program

- Completed Qualification Program
- Key Qual Tests
  - Seal boot hydraulic life cycle test – 20,000 cycles
  - Belleville washer force calibration test
  - Performance tests (at various powers and temperatures)
  - Random vibe (8 Grms in switch open and closed condition)
  - Pyroshock (2000 Gsrs in open condition)
  - Landing loads (48 G sine burst in open condition)
  - Thermal life cycle test – 350 cycles
  - Performance verification tests performed after all life and dynamics tests

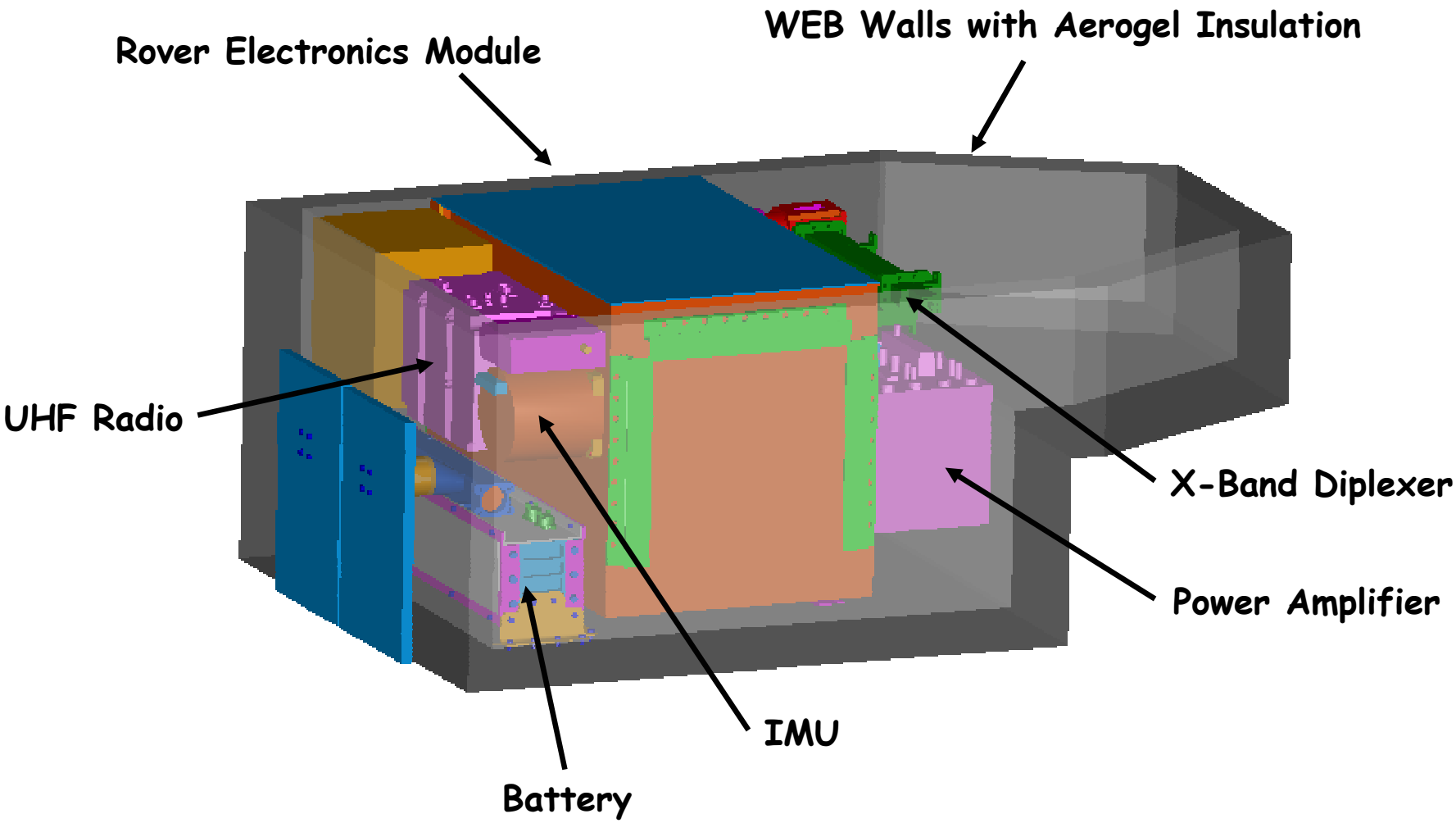
MER Rover


Panoramic Camera
High Gain Antenna
Deployable
Solar Array
IDD
Rock Abrasion
Tool

MER Rover



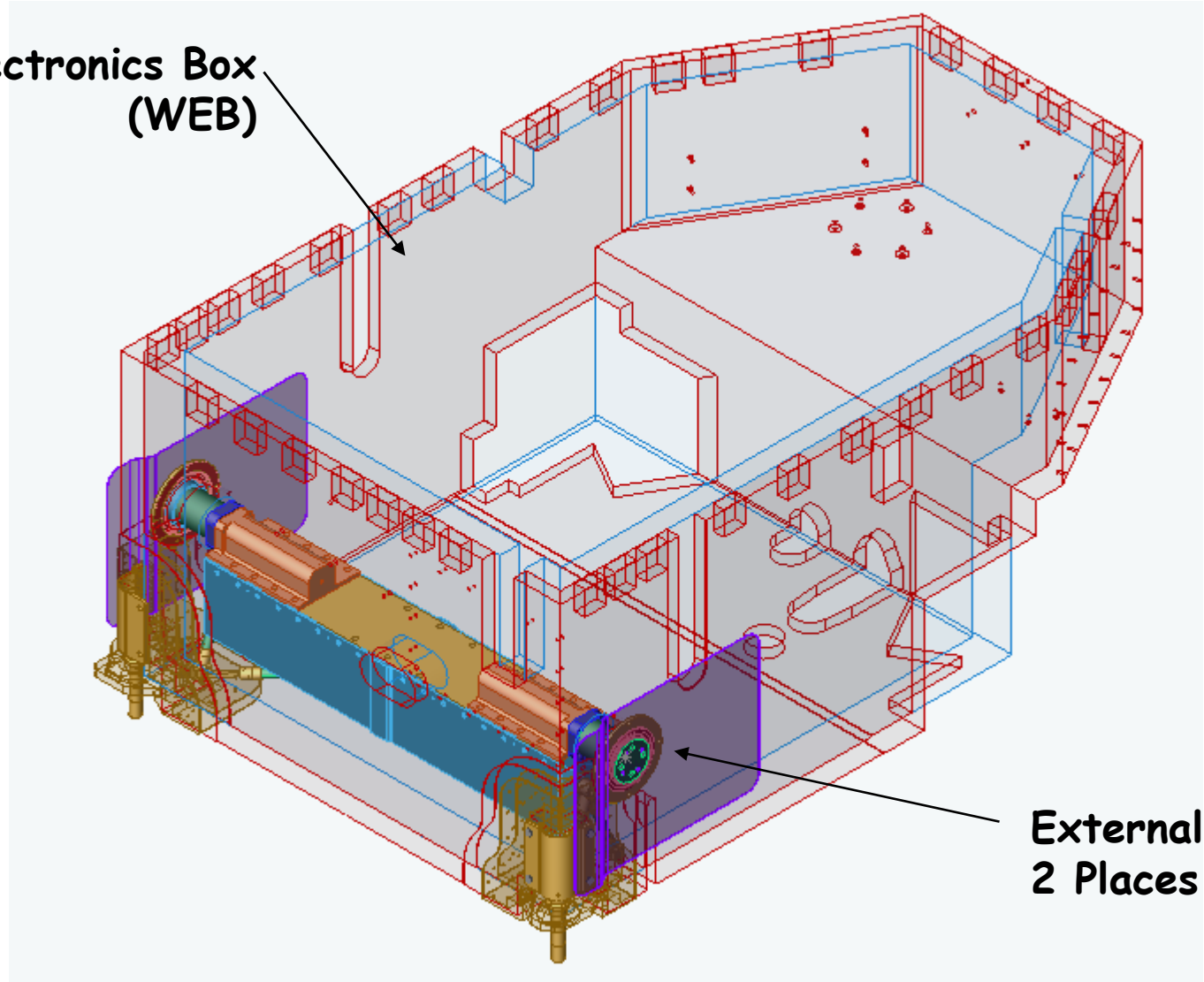
Warm Electronic Box



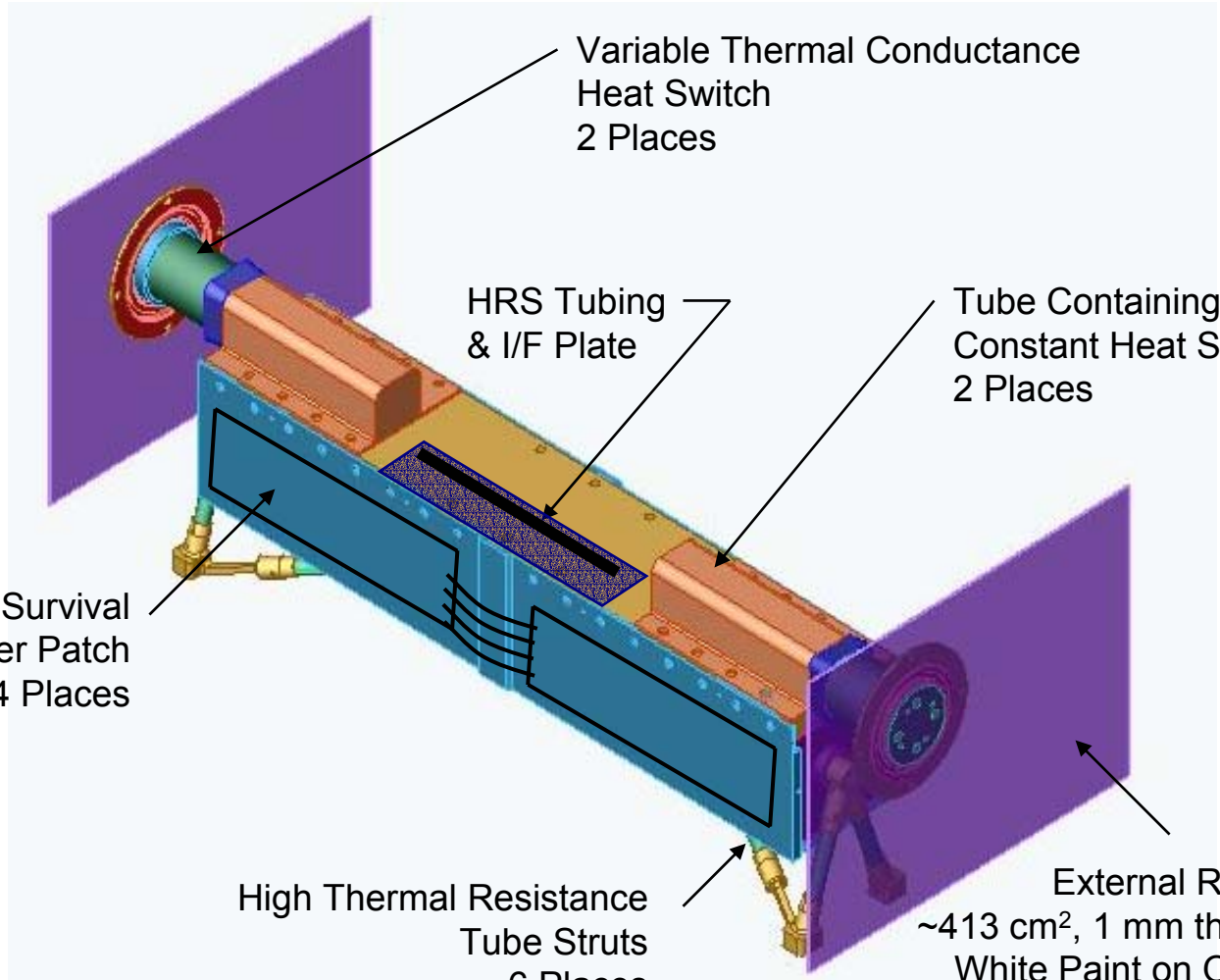
Mars Exploration Rover (MER) Application

- Heat Switch used for the MER Rover Battery Thermal Control System
  - Battery allowable flight temperature limits:
    - surface ops (discharge): -20 °C to +30 °C
    - surface ops (charge): 0 °C to +30 °C
  - Diurnal environment temperatures:
    - Ground: -95 °C min to +20 °C max
    - Atmosphere: -95 °C min to 0 °C max
    - Sky: -150 °C min to –100 °C max
  - Heat sources
    - RHUs provide 6 W continuous
    - nearby electronics contained within same Warm Electronics Box ~2 to 4W
    - battery internal dissipation – temp dependent
  - Thermostatically controlled survival and warm-up heaters, if necessary

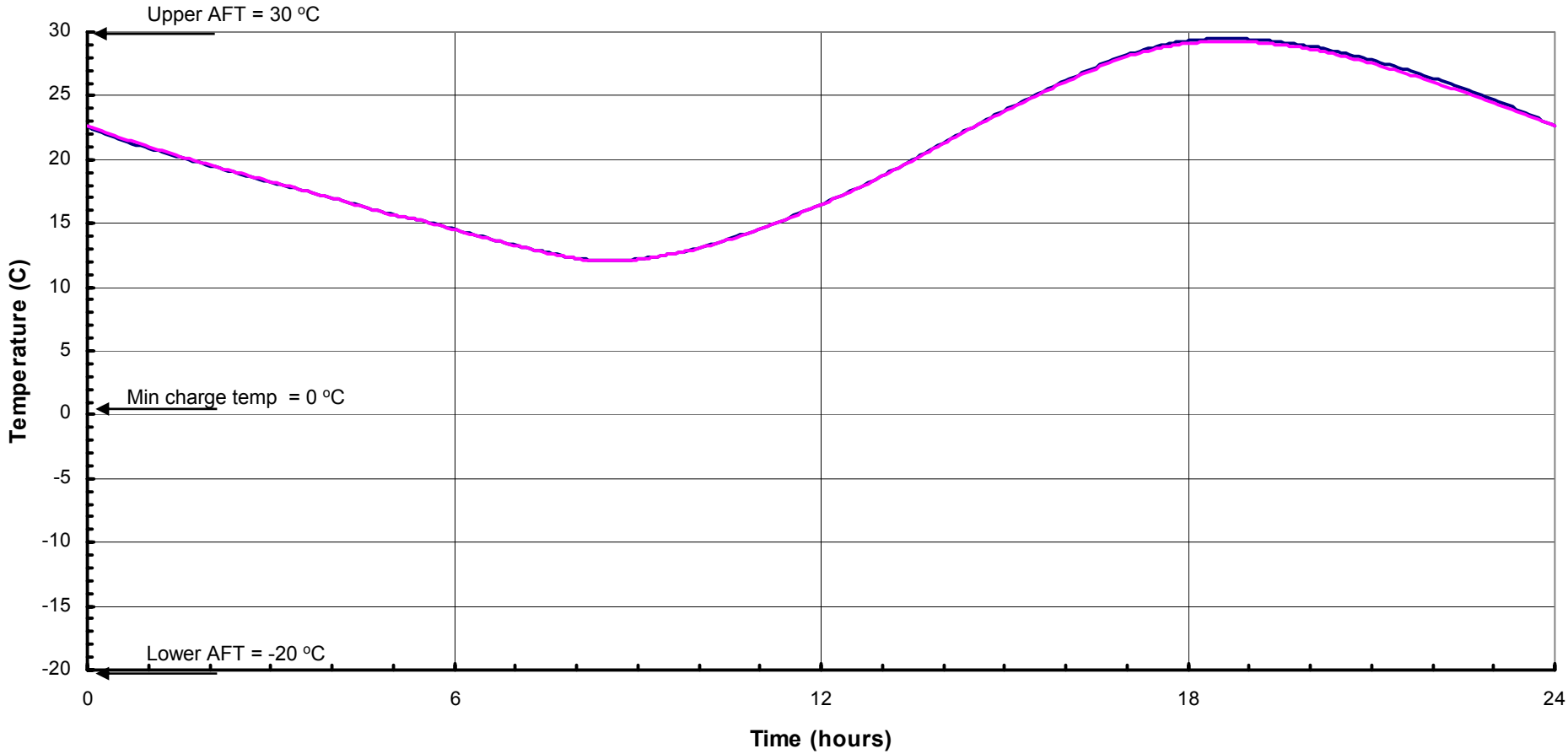
Rover Battery Located in WEB



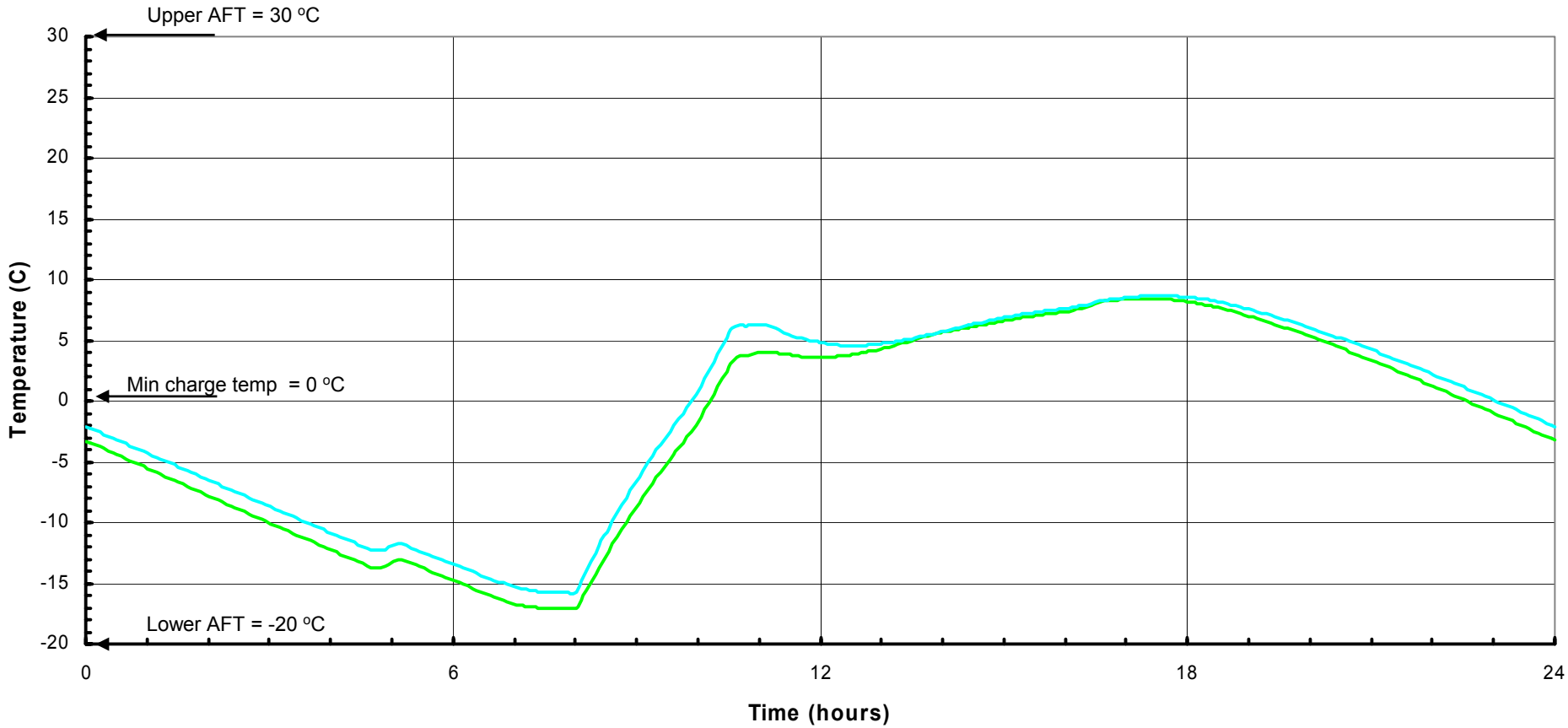
Mars Exploration Rover (MER) Application



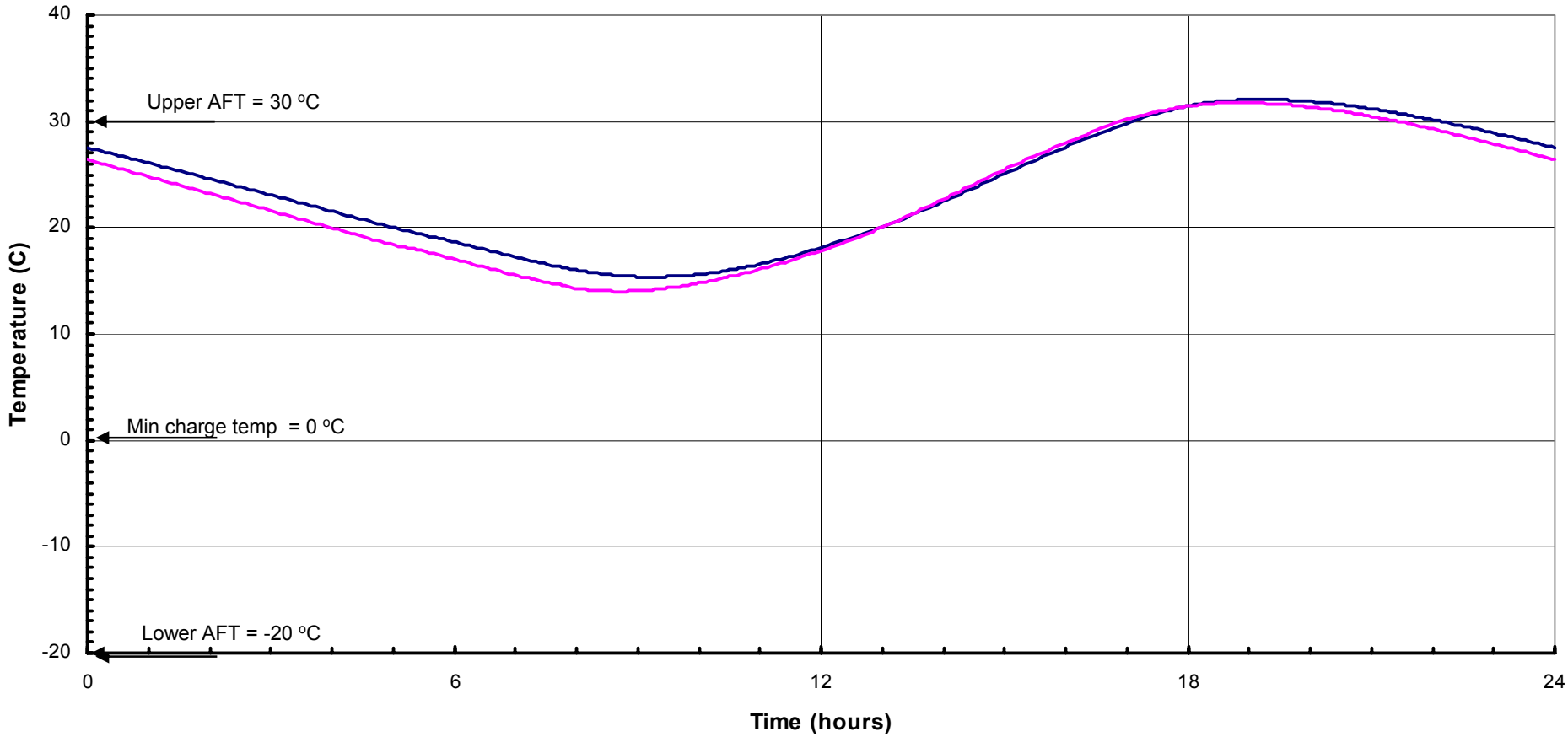
Application Performance – Hot Case Battery Cell Temperature



Application Performance – Cold Case Battery Cell Temperature



Application Performance – Fault Condition of One Switch Failed Open



Heat switch failed closed unlikely

Summary

- Heat Switch functions autonomously and requires no power
- Heat Switch works well with the relatively low dissipations
- Heat Switch has been flight qualified for use on the Mars Exploration Rover (Mid-2003 Launch)
  - Thermal performance exceeds requirements
  - Robust structural design permitted Switch to survive landing loads twice the requirement
- Flight units have passed all Acceptance tests